NEWCASTLE UNIVERSITY SCHOOL OF MARINE SCIENCE AND TECHNOLOGY

Theoretical Optimization of the Length of Surf Ski Kayaks

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This project has been undertaken with the aim of finding a method by which the length of a surfski kayak can be optimised in terms or having least possible resistance. Surf ski kayaking is a highly competitive international discipline that takes place on open ocean, it differs from other forms of kayaking because of the lack of regulations regarding the length of the boats. An aim of this work was to determine if the boats on the market today are fully optimised in terms of having a length with least resistance. Through use of software that incorporates thin ship theory as well as skin friction data from ITTC '57 it was possible to calculate the wave making and frictional resistances for a series of lengths of Wigley hull forms with constant displacement and beam. This allowed a total resistance to be calculated for each length which in turn leads to an apparent 'optimum' length. In terms of boats currently available, it appears from the results that they have indeed been optimised effectively however only for a small weight range of user. A conclusion of this work is that there may well be scope for manufacturers to produce boats better suited for other weight ranges of kayaker or paddler as they are more often known.

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DECLARATION

The author hereby declares that all the subsequent work has been completed by himself with the exception of the various works that have been referenced and acknowledged accordingly

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1.1 Background information

Racing surf ski kayaks are usually used in downwind races on open ocean. They will also usually be in the same direction as the following swell. Because of this the tactics and skill of the paddler are often as or more important than their overall fitness. This is because the fastest way to complete the course will be to use the swell, which will usually be travelling faster than anyone could paddle a boat on the flat, by surfing the waves that come past. Because of this it is important to be able to accelerate the boat to a high enough speed to 'catch' the wave. Once on the wave it is a case of staying there for as long as possible, which will not use too much energy, before sprinting to ‘catch’ the next wave.

After looking into the design of racing surf skis it has become apparent that the design has mostly been done through trial and error methods and the adoption and improvement of previous designs. According to (Lazauskas 1997) this is likely to be due to ‘the monetary rewards of sea kayak and canoe design have never been sufficient to justify tank testing or any other objective and methodical method of hull form development.

The situation of having a wide range of lengths has partly come about due to the lack of rules regulating the designs, if this is compared to the kayaking discipline of flat water sprint racing, where the boat designs are heavily regulated (ICF 2010), some clear differences become apparent. It was not until after the Sydney Olympics in 2000 that a previous minimum width restriction on flat water kayaks was removed. There is however still a maximum length of 5.2m and so all manufacturers make the most of this and design their boats to the 5.2m limit (Nelo 2012; Vajda 2012). Because there is freedom to have any length of surfski this has led to a wide range of designs, from 5m to 6.5m for a single kayak (ICF 2010). The builders of the boats themselves openly say that they feel there isn’t yet an optimum design. Until recently there has been a tendency to have as long a hull as possible without impeding too much on the maneuverability and behavior of the boat while surfing ocean swells this has resulted in a large number of boats being designed at around the 6.5m mark (Vajda 2010; Epic 2012). In more recent years there have been some designers that are moving towards shorter designs that are closer to the length of flat water sprint boats (Carbonology 2012).

> "I am not sure that we have the optimum length and don't believe that any of the manufacturers have it." (Rooyen 2011)

It is this discrepancy between the shorter faster hulls of sprint kayaks and the varying designs of surf skis that is going to be the main subject of investigation in this project. I feel that there should be a small range of lengths that will give an optimum resistance for a given weight of paddler aiming to travel at a given speed.

Because of the lack of previous theoretical research into the specific field of surfski design it will be necessary to look other racing disciplines that have similar issues as well as to more robust research and knowledge that can be found in the broader area of ship hull resistance in which there has been many years of research which is used in the process of ship design on a day to day basis.

1.2 Current knowledge

The primary principle behind this piece of work will be that the total resistance of a vessel can be separated into two main parts, wave making resistance and viscous or frictional resistance (Carlton 2007).

The basis of a lot of current theory behind the resistance of ship hulls comes from Experiments and research conducted by William Froude in the 1800's (Froude 1955). His work and methods have since been widely used. (Michell 1898; Wigley and William Froude Laboratory. 1936; Lewis 1988). They key concepts behind this study are going to be the predicting viscous resistance and wave making resistance and their relative contributions to the total resistance on the boat.

Froude first recognized the need to separate the total resistance into separate components in order to be able to accurately predict the resistance of a ship. Since then his methods have been widely adopted for use in the estimation of the final resistance of ships. This work is also essential for power prediction and choosing the correct size engine for a vessel.

It is Froude's methods that will be used for the prediction of the viscous resistance of the hulls in this project. To find the wave making resistance it is necessary to look to other methods as Froude relied heavily on towing tank testing which goes beyond the scope of this investigation.

1.2.1 Viscous resistance

According to Froude the viscous resistance of a boat is dependent on several factors, wetted surface area, viscosity and ship velocity (Carlton 2007).

- Wetted surface area

The higher the wetted surface area there is the more contact the ship has with the water and therefore there will be more friction on the ship as it passes through the water. However, Froude found that this relationship is not a linear one. His experiments involved towing smooth planks through water and measuring the force required to do so. He found that for a given speed a longer plank would have a lower amount of resistance per unit area than a shorter one. He attributed this to the fact that at the aft end of the plank the water in contact with the plank had acquired a forward motion which meant that some amount of the plank was, in effect, travelling at a slower speed. In his report he said;

> "it is at once seen that, at a length of 50 feet, the decrease , with increasing length, of the frictional per square foot of every additional length is so small that it will make no very great difference in our estimate of the total resistance of a surface 300ft long whether we assume such decrease to continue at the same rate throughout the last 250ft of the surface or to cease entirely after the first 50ft; while it is perfectly certain that the truth must lie somewhere between these assumptions." (Lewis 1988)

While this statement is important for ships it is of little importance to this project as the lengths that will be investigated will only range from 5m to 6.5m (16.5ft 21.5ft).

Froude’s empirical formula for this resistance is shown below.

$$R = f.S.Vn$$

R = resistance kN

S = Surface Area m^2

V = speed m/s

f and n both depend on the length and roughness of the surface (for a given type of suface, f decreases with increasing length and increases with increased roughness)

- Viscosity

The viscosity of water is another of the main contributors to the viscous resistance felt by an object that is moving in water. Temperature has the most noticeable effect on the viscosity of water, as water warms up the molecules gain energy which in turn makes them move around more, this then means that the forces holding them together become less and so it is easier to separate them and have an object move through them. In turn, as the temperature decreases they move around less which makes them more difficult to separate and move through. For the purpose of this study the water temperature will be assumed to be ~25c which is an average temperature of the water in Australia during their summer time where Surfski racing has one of the largest numbers of participants.

- Ship velocity

As seen in Froude's formula on the previous page the velocity of a ship is directly related to the resistance of the ship. As the velocity increase the resistance of the ship will increase proportionally to the velocity to the power of a coefficient calculated by Froude that depends upon the length of the vessel. For the purpose of this work a good estimate would be that the resistance is proportional to:

$$Velocity^{1.85}$$ (Lewis 1988)

This method should work well in the context of this study, it will provide a simply way to get a good estimate of the overall viscous resistance.

1.2.2 Wave making resistance

The calculation of wave making resistance is inherently much more complicated than that of viscous resistance (Carlton 2007). Although this is generally true for typical ocean going vessels such as tankers and cargo ships there are methods that can be used effectively when considering simple hull forms with high length to beam ratios such as those of surfski kayaks (Day, Campbell et al. 2011).

Thin Ship Theory

In 1898 a paper was published entitled ‘The Wave Resistance of a Ship’ (Michell 1898) concerning the prediction of the wave making resistance of simple, fore-aft symmetrical hulls. It builds on W.Froude’s earlier work (Froude 1955) that separates the components of resistance into those of wave making resistance and viscous resistance. He states that

> ‘The conclusion is, therefore, that the course followed by W.Froude, of considering frictional resistance and wave resistance separately and adding the two, will probably be a close approximation to the truth.’(Michell 1898).

Although there are problems with the work of Michell as can be seen by in A Study of Michell's Integral and Influence of Viscosity and Ship Hull Form on Wave Resistance (Gotman 2002) such that at low Froude numbers the Michell integral is very poor at estimating wave resistance especially when used on complicated hull forms. However, as shown in the same paper, once the Froude number exceeds around 0.35, the Michell integral becomes much more accurate especially when used in conjunction with simple hull forms such as the Wigley hull.

This praise for Michell’s method is repeated The Wave Resistance Formula of J.H.Michell and its significance to recent research into hydrodynamics (E.O.Tuck 1989). He concludes his paper with a quote from (Bai 1979) stating

> ‘wave resistance predictions by first-order thin-ship [i.e. Michell] theory are rather consistent in comparison with experimental data and not worse than the envelope of predictions of seemingly more sophisticated methods’

This is followed up by Tuck stating that ‘The situation is not much better today.’ (E.O.Tuck 1989). Here he clearly shows that he thinks that the Michell integral is an effective way of calculating the wave making resistance of ‘thin-ships’.

The Michlet software is a program that puts to use the formula of J.H.Michell as well as ITTC ’57 formula so that both wave making resistance, frictional resistance and therefor a prediction of the total resistance can all be calculated. The program itself requires, among others, input of the offset data and the length, draft, velocity and displacement of the hull.

One theoretical method uses the Wigley hull form which is defined in (Percival, Hendrix et al. 2001) by the formula:

$$y = \pm(1 - 4x^2)(1 - 256z^2)/20$$

And by (Wang and Zou 2008) as

$$y = 0.5B(1 - (z/D)^2)(1 - 4(x/L)^2)$$

(Zhang and Chwang 1999) Discusses the use of a Wigley hull along with CFD to estimate wave resistance as an alternative to towing tank testing. They conclude that the inviscid flow Euler method can predict the wave form along the hull however it does have limitations. For example viscosity is ignored in their study which does lead to errors in the predictions especially when flow separation occurs. They suggest that if this is the case then the Navier-Stokes method should be used instead. The Wigley hull is also discussed in (Wang and Zou 2008) as a method for estimating the wave making resistance of a trimaran. They suggest that the simplified hull shape of the Wigley hull correlates well to observed experimental results and they conclude that their method of CFD analysis of the Wigley hull is a ‘feasible and effective way to solve the trimaran wave-making problem’(Zhang and Chwang 1999).

1.3 Literature Review

The Wave Resistance of a Ship – (Michell 1898)

Although this paper is now 114 years old it provides the details of the triple integral devised by J.H Michell that allows a prediction of the wave making resistance of a ship with a parabolic waterline to be made.

The paper was published in Australia in the Philosophical magazine. It is an unfortunate truth that no developments were made on the paper for another 20 to 30 years when the likes of Sir Thomas Havelock (Havelock 1965) were to use it as a basis for parts of their own work. This is possibly because the paper wasn't published in a journal that was solely committed to work in the naval architecture world. Had this have been done, it might have resulted in the paper being read and discussed by a larger number of people who were working in the same field of interest.

The paper discusses the approximations that must be made such as how the effects of friction must be neglected so it can be assumed that the fluid is inviscid and therefore irrotational which allows the presence of a velocity potential to exist which is a fundamental part of formula.

Of all the papers reviewed it is this one that has the most significance to this project as it is the basis for work that has continued for over a century and probably will continue to be used into the future. It has been acclaimed in several other papers (E.O.Tuck 1989; Tuck 2000; Gotman 2002; Lazauskas 2008) as providing a method that to this day continues to be, as, or more accurate at predicting wave making resistance than any method that is currently available. It has to be said that this is not because the Michell integral provides the perfect method for such calculation, but more because the other methods (towing tank tests, CFD) also have inherent flaws within them.

The Wave Resistance Formula of J.H, Michell and its Significance to Recent Research in Ship Hydrodynamics –(E.O.Tuck 1989)

This paper is split into three sections, a historical summary of the life of J.H Michell, a summary of the paper on ship waves by J.H Michell and modern developments on the formula of Michell.

It is the second two sections that are most useful to this study. Within the space of four pages the second section gives a clear and concise summary of Michell integral (Michell 1898) is given, this includes its derivation, assumptions made in order for it to work, as well as discussing similar work that was being done at around the same time.

The final section discussing, ‘modern developments’, is useful for a number of reasons. Firstly it does very well at discussing both the advantages as well as the disadvantage of the integral. Tuck points out that the integral does not very effectively predict the wave resistance for vessels travelling at low speed at which the waves generated are not close in length to that of the vessel. He discusses that this may be one of the reasons that the Michell integral is not used more widely as it is this area that a large number of naval architects will be focused on improving.

This final section is also useful as it directs the reader to other later work in which the Michell integral was a central part, the work of the likes of C.Wigley and Sir Thomas Havelock (Havelock 1965). There is one other problem which is that is there is no discussion of where the experiment results, which are used as a comparison of the Michell integral, have come from.

Study of Michell’s Integral and Influence of Viscosity and Ship hull Form on Wave Resistance – (Gotman 2002)

This study looks at the peculiarities of the wave making resistance predictions of Michell’s integral at low speeds as well as the influence of viscosity on the interaction between bow and stern wave systems.

The paper demonstrates that, while Michell’s integral compares well with measured figures for wave making resistance at Froude numbers greater than around 0.37, below that point the predictions of Michell integral (Michell 1898) oscillates significantly . This anomaly severely limits the integrals effectiveness at predicting the wave making resistance at a range of Froude numbers that is vitally important to a lot of naval architects.

Although this is the case Gotman also goes on to demonstrate that there is also a limit to the precision of towing tank tests at predicting wave resistance. He references the work of (Bai 1979) who collected experimental data for various towing tank test on the same Wigley hull and plots both the maximum and minimum curves of the wave resistance against Froude numbers as well as the Michell integral prediction for the same hull, the Michell results fit right between the maximum and minimum towing tank results.

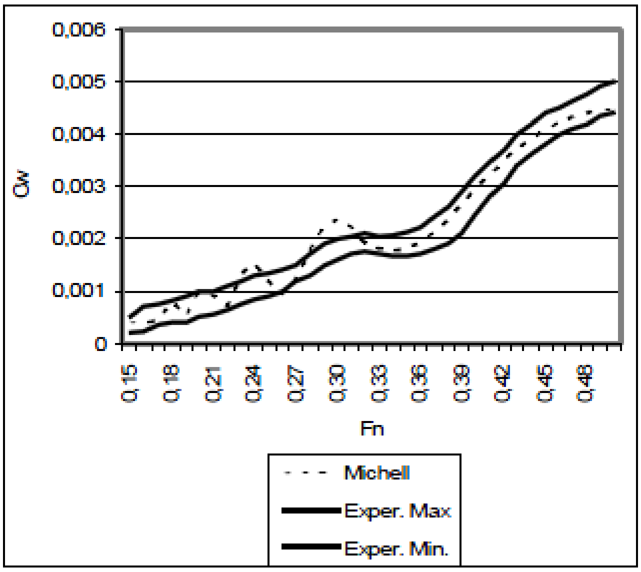


Figure 1. A comparison between the minimum and maximum measured coefficient of wave resistance of a Wigley hull and a prediction of the coefficient of wave resistance the same Wigley hull using Michell's integral (Gotman 2002)

Gotman continues to by going on to discuss the work of (Sharma 1969) who, among other areas investigated what constituted a 'thin' ship. Shama's work involved towing tank tests of a parabolic hull with a L/B ration of 20, the results from this fit very well with those of the Michell integral for all Froude numbers over 0.38.

In conclusion, although not the primary aim, this paper gives a helpful and concise insight into the effectiveness of Michell's integral in predicting wave making resistance by bring together the work of several other authors work.

<u>Hydrodynamic Drag of Small Sea Kayaks (Lazauskas 1997)</u>

Of all the papers viewed, this is the one that is closest in aims, method and subject to this project. The paper looks to calculate and compare the total resistance (wave making plus frictional) of 4 single seat sea kayaks. In order to do this the authors use the Michlet software which its self uses ITTC '57 (ITTC 1957) to calculate the frictional resistance as well as Michell's integral in order to estimate the wave making resistance.

The authors compare the calculated resistances of the Michlet software with that of experimental results and claim to find very accurate readings at lower speeds with increased errors as the speed increases. These errors are suggested to be due to the hulls squatting or holding angles of trim.

There is a discussion of the alternatives to the methods used, towing tanks are ruled out as being too expensive to be viable as there is not a large enough market or incentive to make hull optimization of this sort a worthwhile venture. The claim that this has led to boats being designed simply through ‘test paddlers’ trialing the boats and giving feedback. They point out numerous issues which are beyond the control of designer such as the inability to exactly replicate a test as well as not being able to quantify the differences between two designs in a reliable or useful manner.

The conclusion of this paper is that there is a strong correlation between the predicted values and the test values and that the authors think that the Michlet software could ‘provide designers in the field with economical and reliable tools’ for developing hull forms.

Realistic evaluation of hull performance for rowing shells, canoes, and kayaks in unsteady flow (Day, Campbell et al. 2011)

This paper is mostly based around a discussion of the prediction of the resistance of rowing shells and how it is effected by a number of factors such as water depth and accelerations that occur when rowing. Although the main subject is not instantly of use to this project there are parts that are.

By discussing other work such as that of (Lazauskas 1997) and (E.O.Tuck 1989) it gives them more approval and recognition which strengths the argument for using their work in this paper.

Furthermore the authors go on to use a Wigley hull form in order to simulate that of a rowing hull in order to reduce the computational power required in order to predict the wave making resistance. This is interesting as using a Wigley hull form to simplify calculations is a possibility for this project.

Principles of Naval Architecture volume 2 Resistance, Propulsion and Vibration - (Lewis 1988)

The Principles of Naval Architecture gives a broad but concise overview of the theory and history behind the calculation of the resistance of ships. It looks into the theories that were first shown to be true by Froude as well as the work of many other leaders of the field. Although the book is good it is limited somewhat because it is starting to become out of date in some areas. The advances in computational fluid dynamics (CFD) now go far beyond what is described in the book and it is when information related to this area is needed that it is necessary to look elsewhere.

Numerical research on wave-making resistance of trimaran - (Wang and Zou 2008)

This paper is closely matched with the aims of my project in terms of its use of the Wigley hull to optimise a hull form. It does differ in that it is studying a trimaran and this project is optimising a surfski but a lot of the theory is very similar.

Numerical research on nonlinear ship waves and wave resistance calculations - Zhang, D. and Chwang, A. T.

This paper, as it says, looks into numerical methods of calculating the wave resistance of a ships hull. It looks more deeply into the difference between the Euler and Navier-Stokes formulae when used in CFD and their limitations.

Throughout the paper the results of the same tests are shown. They state that the limitations of the Navier-Stokes equation are that it is too time consuming, however this article is now 12 years old and both computational power and the knowelegde behind CFD has increased greatly since then so this may not be as much of an issue as it is shown to be. The limitations they give for the Euler method are that when there is flow separation the accuracy of the results deminishes rapidly.

1.4 Summary

Ship resistance is a subject on which there has been a huge amount of research since the work of William Froude in the 1800's. The subject is a complex one and, as such, in order to predict the resistance of any given vessel, there almost always will need to be assumptions made whether that be in towing tank tests, CFD modelling or when using methods such as Michell's integral and thin ship theory.

Based on the literature studied, the wide and successful use of thin ship theory and Michell's integral in similar studies to the one being undertaken here indicate that they are useful tools in terms of wave making resistance prediction. From reading through the various other reports it is also clear that although there are other method such as towing tank test as CFD, they too have their own problems and are by no means perfect.

The Wigley hull form is also discussed in multiple papers and sources as a providing a valid method by which a prediction of the resistance of a slightly more complicated hull form can be made.

1.5 Literature Review Bibliography

Bai, K. J. (1979). "Overview of Results."

Carbonology (2012). "Carbonology Sport Surf Ski Specifications."

Carlton, J. (2007). Marine propellers and propulsion. Amsterdam ; Oxford, Elsevier Butterworth-Heinemann.

Day, A., I. Campbell, et al. (2011). "Realistic evaluation of hull performance for rowing shells, canoes, and kayaks in unsteady flow." Journal of Sports Sciences **29**(10): 1059-1069.

E.O.Tuck (1989). "The Wave Resistance Formula of J.H.Michell and its Significance to Research in Ship Hydrodynamics."

Epic (2012). "Epic V10 Specification."

Froude, W. (1955). The Papers of William Froude. London, Institution of Naval Architects.

Gotman, A. (2002). "Study of Michell's Intergral and Influence of Viscosity and Ship Hull Form on Wave Resistance." Oceanic Engineering International **6**(2): 74-115.

Havelock, T. (1965). The collected papers of Sir Thomas Havelock on hydrodynamics. Washington,, Office of Naval Research Dept. of the Navy; for sale by the Superintendent of Documents U.S. Govt. Print. Off.

ICF (2010). "Canoe Ocean Racing." Retrieved 20/11/2011, 2011.

ITTC (1957). "Skin Friction and Turbulence Stimulation."

Lazauskas, E. T. a. L. (2008). "Drag on a Ship and Michell's Integral."

Lazauskas, L., Winters, J and Tuck, E.O (1997). "Hydrodynamic Drag of Small Sea Kayaks."

Lewis, E. V. (1988). Principles of Naval Architecture. Jersey City, NJ, The society of Naval Architects and Marine Engineers.

Michell, J. H. (1898). "The Wave Resistance of a Ship." Philosophical Magazine **5**: 106-123.

Nelo (2012). "Nelo kayak specifications."

Percival, S., D. Hendrix, et al. (2001). "Hydrodynamic optimization of ship hull forms." Applied Ocean Research **23**(6): 337-355.

Rooyen, H. V. (2011). R. Baker.

Sharma, S. D. (1969). "Some Results Concerning the Wavemaking of a Thin Ship." J Ship Research **13**: 72-81.

Tuck, E. O., Scullen, D.C and Lazauskas, L (2000). "Ship-Wave Patterns in the Spirit of Michell." Paper presented at IUTAM 2000, Birmingham.

Vajda (2010). "Vajda ORCA elite Pro Specification."

Vajda (2012). "Vajda sprint kayak specification."

Wang, H. and Z.-j. Zou (2008). "Numerical research on wave-making resistance of trimaran." Journal of Shanghai Jiaotong University (Science) **13**(3): 348-351.

Wigley, W. C. S. and William Froude Laboratory. (1936). The theory of the bulbous bow and its practical application. Newcastle upon Tyne

London, North East Coast Institution of Engineers and Shipbuilders ;

E. & F. N. Spon.

Zhang, D. and A. T. Chwang (1999). "On nonlinear ship waves and wave resistance calculations." Journal of Marine Science and Technology **4**(1): 7-15.

2. INTRODUCTION

2.1 Aims of the section

The aim of this introduction is as follows:

1. To give a brief overview of the sport of surfski kayaking
2. Detail the reasoning behind undertaking this project
3. Give a brief discussion of the principals on which the project will be based
4. Set out the aims of the project as a whole

2.2 The Sport of Surf Ski Kayaking

Surfski kayaking is an international kayaking discipline major events happening all over the world. The races in general will involve racing on open ocean but they vary considerably vary in terms of length and course. An example race is the Ohana Mana Cup which is part of the ICF ocean racing world cup, the 2011 race was 37km with a 2000euro prize for the winner (a large sum relative to other kayak disciplines). The racing its self is very tactical as a lot of time can be gained by being able to read the environment well.

2.3 Reasoning for undertaking this project

What differentiates surfski racing from almost all other kayaking disciplines, sprint, marathon, slalom, wild water racing, canoe polo, is that there are no rules regulating the length of the boats used (ICF 2010). Because of this and the trial and error way in which surfski design has evolved there are currently a wide variety of different lengths available on the market today (Vajda 2010; Carbonology 2012; Epic 2012).

Although there are a wide range of lengths available, almost all boats aimed at high performance athletes and not beginner or intermediate paddlers are within the 6.4m to 6.5m length range.(Vajda 2010; Epic 2012) What also differentiates surf ski boats from other disciplines such as sprint or slalom racing is that the manufacturers don’t offer boats of different sizes for paddlers of different weights but instead seem to go with a ‘one size fits all’ approach. Figure 2 on the following page shows the wide range of boats available to Sprint and marathon paddlers depending on their weight.

Choose the right boat for you

To choose a boat find out your weight and then select the required stability with 1=Least stable and 10=Most stable

	Weight in Kg												
Stability	40	45	50	55	60	65	70	75	80	85	90	95	100
1					Infusion -Vajda		Supersonic 01 - Vajda						
	Sprint 55 - Elio			Sprint 65 - Elio									
2	Cougar - Marsport						Jaguar - Marsport						
					Tatic - Kirton				Teknik - Kirton				
				Vanquish III M - Nelo				Vanquish III L - Nelo		Vanquish III XXL - Nelo			
					Tiger - Struer				Cleaver - Struer				
							Cleaver X - Struer						
							Alpha - Marsport						
			Beta - Marsport										
						Orca M - Hody		Orca L - Hody		Orca XL - Hody			
3						X - Lancer - Struer							
					Joker - Struer								
				Vintage - Nelo									
4					Typhoon - Kirton								
	Zeta - Marsport						Eta - Marsport						
									Lancer - Struer				
					Ranger - Kirton								
5					Javelin - Marsport								
6							Puma - Elio						
					Tor - Kirton								
			Raven - Marsport										
7					Espada - Struer								
			Epsilon - Marsport										
8					Hobby MK 2 - Marsport								
9					Talisman - Kirton								
							Laance - Marsport						
10		Tarka - Kirton				Tempest - Kirton							
								Tercel - Kirton					

Table 1 Some of the kayaks available to kayakers of different weights (Club 2011)

2.4 Fundamental principles of the Research

This project is based upon the principals set out by (Carlton 2007) that say that the total resistance of any ship in made up by two separate contributors, viscous resistance and wave making resistance. In the case of this project viscous resistance is simplified further to just include just friction resistance. It was William Froude who first came up with the idea that ship resistance can be broken down in such a way. He came up with the theory whilst predicting ship resistance using scale models, the details of which can be found in the compilation of his work, ‘The Papers of William Froude’ (Froude 1955).

2.5 Project Aims

The primary aims of this project are as follows:

1. Find an effective method of estimating the wave making and viscous resistance of a surfski.
2. To predict the optimum length a surf ski for a given velocity and displacement.
3. To investigate the effect, if any, that displacement has on the optimum length of a surfski.
4. To relate the estimated optimum lengths to the boats that are currently on the market.

2.6 Predictions

It is predicted that the optimum lengths will be somewhere between the 5.2m restriction on flat water racing kayaks (ICF 2010) and 6.5m which is around the maximum length for most modern surfskis (Vajda 2010; Epic 2012). This will be done by calculating the wave making resistance, viscous resistance and total resistance.

3. METHOD

3.1 Aims of the section

This section sets out to present to describe the following

- The reasoning behind the choice of method used.
- A description of the method
- Information about the software used as well as a guide to using it.
- A discussion of assumptions and inaccuracies.

The task for this section is to find a method that will result in a prediction of both the wave making resistance and the frictional resistance of a surf ski. This will require having the hull form of a surf ski or that of one that is very similar as well as a way of using that hull shape to calculate its resistance.

3.2 Hull choice

The hull chosen had to be one that could have its length varied without having any adverse effect upon the hydrodynamics. This put the 'Wigley' hull in a strong position as its uniform parabolic shape would make it very consistent if increasing or decreasing its length.

The choice of hull on which to test was down to a number of factors. It is known that the Michlet Software works best with simple parabolic hulls and there has been substantial amounts of testing completed using the Michell integral and the Wigley Hull which is itself a parabolic hull. It is also important that the hull being modelled is similar to that of the surfski hull designs that this work is attempting to simulate.

As the Wigley hull form is proven to provide both good results with the software in question as well as a good estimation of the design of the boats in question. As can be seen from Figs 2 and 3 there is a very strong visual similarity between the Wigley hull and that of a surf ski. For these reasons it has been chosen as a suitable hull form for the tests.

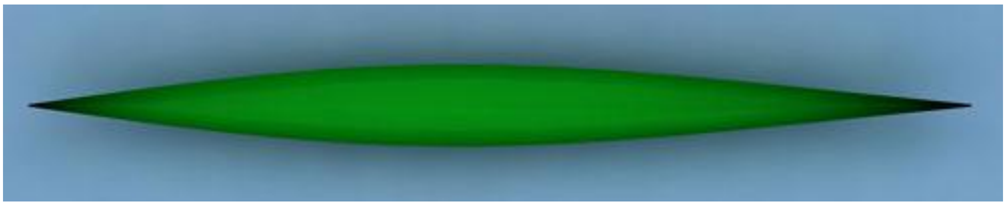


Figure 2. The hull shape of a typical surf ski (Multisportkayaks 2008)

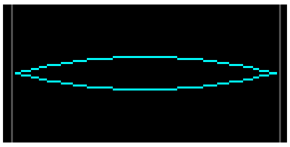


Figure 3. Wigley hull used in Michlet (Lazauskas 2011)

3.3 The Michlet Program

The Michlet program(Lazauskas 2011) has been chosen in order to find the wave making, frictional and total resistance for a range of lengths of surfski with a constant beam of 0.45m. This program was chosen due to it effective use in other similar projects relating to small vessels such as other types of sea kayak(Lazauskas 1997). Although there are undoubtedly inaccuracies associated with certain aspects of the program most of these have been reduced as much as possible. It can be fairly sure that equal levels of inaccuracies can be associated with other possible methods such as towing tank tests. For example, there are many scaling effect problems associated with towing tank methods as well as issues with production of models(ITTC 1957).

The calculations will be carried out for 3 different models with three different displacements which are shown as models 1, 2 and 3 in the Table 2.

Model	1	2	3
Mass of Paddler (kg)	69.5	90	110.5
Mass of Boat (kg)	12.5	12.5	12.5
Total mass (kg)	82	102.5	123
Displacement (m3)	0.8	0.1	0.12

Table 2. Masses and displacements for each model tested

By looking into the resistance of a range of lengths of vessel for each of the given displacements it will give hopefully give an idea of how length affects the total resistance for each. The range in lengths is planned to be from 4m to 10m in varying steps of between 0.5m and 0.05m. The size of step will depend on if the length appears to be approaching an optimum. This should lead to the ability to make conclusions concerning whether or not the boats currently on the market are already at their optimal length or if indeed it would be beneficial to have shorter designs.

With the exception of (Carbonology 2012) the current situation in terms of boats available is that of one size fits all and there seems little thought into the requirements of lighter paddlers, it is my thought that a lighter paddler would be better suited to a shorter boat which will most likely offer a reduction in total resistance.

3.4 Method

The method itself is very simple; it involves using the Michlet program to calculate the wave making, frictional and total resistance for each length. Details of the method for using the Michlet software can be found in appendix 1, A Guide to Using the Michlet Software (Baker 2012). These results will then be plotted and a length with a minimum resistance will be found.

3.5 Assumptions and inaccuracies

There are several assumptions that had to be made to carry out this project as well as several factors that have been ignored.

3.5.1 Trim

It was assumed that there was zero angle of trim for each of the vessels for the purpose of the tests. Whether or not there would be would have to be found out experimentally and how much it would affect the results if there was is difficult to say. It is fair to say that any angle would be very small and as such it is unlike that it would have much of an effect on the results and if it did it is unlikely to significantly change the findings. It is true however that the motion of the paddler will affect the trim of the boat (Day, Campbell et al. 2011), although this would be an inconsistency it is a constant inconsistency, that is to say that it would be the same for each length tested and therefore will be neglected.

3.5.2 Squatting or lift

It was assumed that there would be no squat or indeed lift. Unlike trim, it is actually quite likely for there to be some amount of lift or squat. In real terms when a surfski is moving at speed it will experience lift (Lazauskas 1997), which will in turn reduce the wetted surface which will clearly reduce the total resistance. That being said, to actually quantify this would most likely require physical tests and as the amount is also likely to change for each length the tests would need to be carried out for each length to be tested. Because this is outside of the scope of this project it was also neglected.

3.5.3 Wind resistance

It is true that wind resistance would begin to contribute a noticeable amount towards the total resistance when travelling at speeds at which the calculations were made. This has however been ignored for the purposes of this project, the reason being is that air resistance is proportional to the forward projected area above the waterline. As the beam of the surf ski is not intended to change with length and also the projected area of the paddler is significantly higher than that of the surfski(Carlton 2007), it is an accurate assumption to make that the air resistance will not affect the outcome of the results.

3.5.4 Spray and waves

The values obtained from the Michlet program assumed that there was flat calm water, this is a necessary assumption that has to be made in order for Michell's integral to work (Michell 1898). In term of surfski racing it is obvious that the boat will very rarely be used in this situation and in fact quite the opposite is true, surf skis operate in a very dynamic environment (ICF 2010). Although this will create added resistance, it will cause added resistance for all lengths and as it is such a variable and dynamic case it would be very difficult to try to take this into account therefore it has also been neglected.

3.5.5 Infinite water depth

In order for the Michell integral to accurately predict the wave making resistance it is required infinite water depth is assumed (Michell 1898). As surf skis are used on open ocean, so mainly deep water, and their draft is very low, from 6cm to 12cm so, it is reasonable to assume that the sea floor will not have any effect on their wave making resistance.

3.5.6 That the resistance of a Wigley hull can be compared to those of a surfski

This is an important assumption as it is central to the project as a whole. This is a difficult assumption to prove without data from model tests. It can be said that the two types of hull are similar in characteristics with the exception that actual surfski designs aren't fore-aft symmetrical in terms of volume. The added volume toward the bow will be mostly above the waterline to reduce the chances of the bow being fully submerged by waves, it is fair to say that the hull shape below the waterline will be relatively similar to that of a Wigley hull for. As such, as far as can be said without test result data, the two will be likely to have similar resistance characteristics and any differences should be the same across all of the lengths tested.

3.5.8 Form Factor

It is possible to account for form factor using formula found in (Holtrop and Carter 1977) this would improve the accuracy of the results however as the form factor will most likely be very similar for each length of hull it shouldn't drastically effect the final results.

3.5.7 Dynamic motions will not have an effect on total resistance.

Experience of using kayaks suggests that it is near impossible that some, if not all, of the dynamic motions of yaw, pitch, heave, roll, sway or surge will occur. It is also likely that they each will have some effect on the overall resistance as they will affect the way in which the water moves around the hull of the vessel(Froude 1955). These motions are being neglected for two main reasons:

1. Their effects are likely to be a very small proportion of total resistance
2. Accurately predicting and quantifying the effect that these motions would have on the total resistance would be a very complicated and difficult task.

3.6 Summary of the method

The method used is a simple one based on the theory that total calm water resistance for a simple hull with no appendages is equal to the combination of the frictional and wave making resistance of the hull. This will be done by using Michlet (Lazauskas 2011)software that uses the theories of (Michell 1898) as well as (ITTC 1957) procedures for calculating the wave making and frictional resistance respectively.

The software will be used to calculate a frictional, wave making and total resistance for a range of lengths in which it is predicted that there will be an optimum length. In order to better understand, the effect that displacement has on optimum length this procedure will be done for three different displacements which will simulate a ‘light’, ‘medium’ and ‘heavy’ weight paddler, see Fig 5.

There are a large number of assumptions that had to be made in order to make the investigation feasible. These assumptions are mainly accounted for because the wave making resistance has to be calculated for the hull on flat calm water. These assumptions are difficult to get around as there are currently no methods for predicting the wave resistance when the oncoming water isn’t flat or uniform.

4. RESULTS

4.1 Aims of this section

- Provide a sample of the results taken
- The optimum length found for each displacement.
- The effect on resistance of increase or decreasing the length above or below the optimum length.
- How the contribution of wave making resistance changes with length.

The Michlet software outputs a different graph for wave making, frictional and total resistance for each length and displacement. As only one number is taken from each graph and there are 177 graphs in total that would each take up around half a page it does not make sense to reproduce them in the main report, because of this an example graph for each of the three resistances is reproduced in the appendix 2.

The full table of results in shown in appendix 3 which is found on the accompanying DVD. While a more brief set of tables is shown in Figures 3, 4 and 5 with the lengths with the lowest total resistance highlighted.

82kg Displacement				
length	draft	Resistance		
		Wave Making	Frictional	Total
2.14	0.18692	0.09	0.0317	0.1217
2.675	0.14953	0.0586	0.0338	0.0924
3.745	0.10681	0.0251	0.0386	0.0637
4	0.1	0.0209	0.0398	0.0607
4.5	0.08903	0.0149	0.0423	0.0572
4.9	0.08163	0.0115	0.0444	0.0559
5	0.08	0.0108	0.0449	0.0557
5.1	0.07843	0.0102	0.0454	0.0556
5.2	0.07692	0.0096	0.0459	0.0556
5.3	0.07547	0.0091	0.0465	0.0555
5.4	0.07407	0.0085	0.047	0.0555
5.5	0.0727	0.0081	0.0475	0.0556
5.6	0.07143	0.0076	0.048	0.0556
5.7	0.07017	0.0072	0.0486	0.0558
5.8	0.06897	0.0068	0.0491	0.0559
6	0.06667	0.0061	0.0501	0.0562
6.5	0.06154	0.0047	0.0528	0.0575
8.025	0.04985	0.0022	2.64396	0.063

Table 3 Results taken for a series of Wigley hulls with 82kg displacement and 0.45m beam travelling at 4.2m/s.

102.5kg Displacement				
length	draft	Resistance		
		Wave Making	Frictional	Total
4	0.125	0.0737	0.0304	0.0433
4.5	0.111	0.0674	0.0218	0.0456
5	0.1	0.064	0.016	0.048
5.5	0.091	0.0623	0.012	0.0504
5.6	0.089	0.0622	0.0113	0.0509
5.7	0.088	0.0621	0.0107	0.0514
5.8	0.086	0.062	0.0101	0.0518
5.9	0.085	0.0619	0.0096	0.0523
5.95	0.084	0.0619	0.0093	0.0526
6	0.083	0.0619	0.0091	0.0528
6.1	0.082	0.062	0.0086	0.0533
6.2	0.081	0.062	0.0081	0.0538
6.3	0.079	0.0621	0.0076	0.0543
6.4	0.078	0.0622	0.0072	0.0548
6.5	0.077	0.0623	0.007	0.0553
7	0.071	0.0633	0.0054	0.0579
7.5	0.067	0.0647	0.0043	0.0604
8	0.063	0.0663	0.0033	0.063

Table 4. Showing details of the results taken for a series of Wigley hulls with 102.5kg displacement travelling at 4.2m/s.

123kg Displacement				
length	draft	Resistance		
		Wave Making	Frictional	Total
5	0.12	0.022	0.0512	0.0732
5.3	0.113	0.0184	0.0526	0.071
5.95	0.101	0.0129	0.0556	0.0685
6	0.1	0.0126	0.0558	0.0684
6.1	0.098	0.012	0.0562	0.0682
6.2	0.097	0.0113	0.0568	0.0681
6.3	0.095	0.0107	0.0572	0.0679
6.4	0.094	0.0101	0.0577	0.0678
6.5	0.092	0.0096	0.0582	0.0678
6.6	0.091	0.0092	0.0586	0.0678
6.7	0.09	0.0087	0.0592	0.0679
6.8	0.088	0.0083	0.0596	0.0679
6.9	0.087	0.0079	0.0601	0.068
7	0.086	0.0076	0.0606	0.0682
7.1	0.085	0.0072	0.0611	0.0683
7.2	0.083	0.0069	0.0615	0.0684
7.5	0.08	0.0059	0.063	0.0689
8	0.075	0.0046	0.0655	0.0701

Table 5 Showing details of the results taken for a series of Wigley hulls with 123kg displacement travelling at 4.2m/s.

4.2 Optimum lengths

It can be seen from fig 4 that as displacement increases so does length that will offer the least resistance.

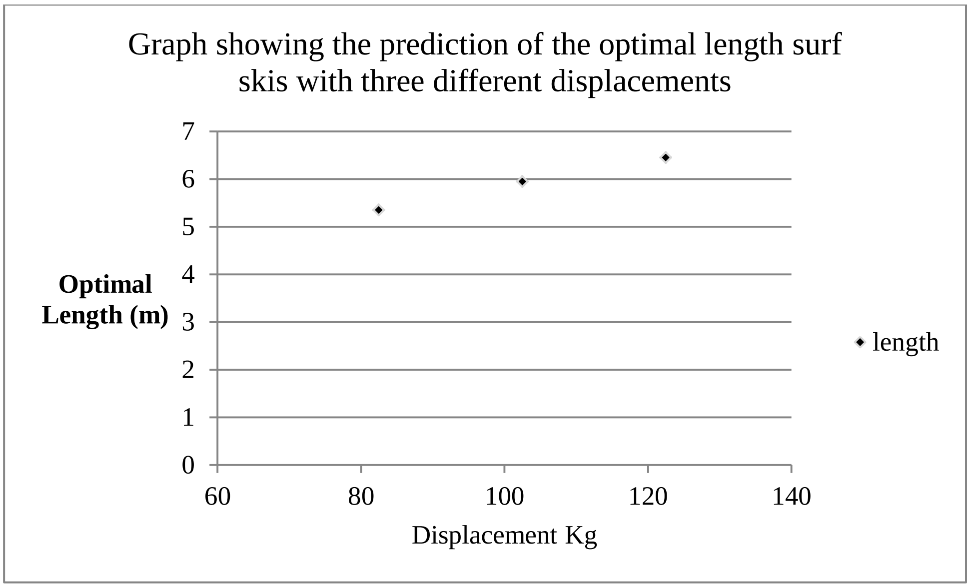


Figure 4 Plot of predicted optimal lengths against desplacement

To clarify, the optimum lengths found for each displacement is shown in the Table 6.

mass	Length (m)
82.5	5.35
102.5	5.95
122.5	6.45

Table 6 Optimal length for each displacement modelled

4.3How the effect of wave making resistance changes with increasing length

From the results it is apparent that the contribution of wave making resistance to the total resistance reduces significantly as length increases. This is shown in Fig 5. From the results it can also been seen that for the displacements tested, the optimal length comes about when the wave making resistance accounts for around 14-16% of the total resistance. A trend line has been added to demonstrate the exponential manner in which the effect of wave making resistance decreases.

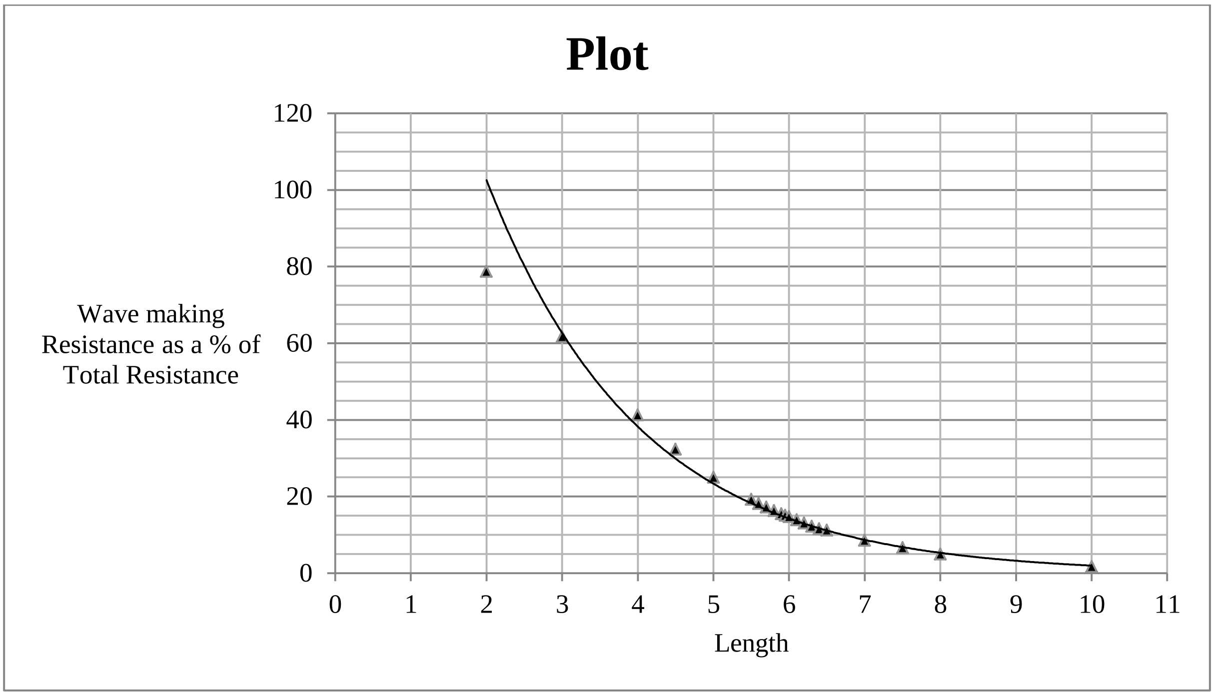


Figure 5 The wave making resistance as a percentage for the hull with 102.5kg displacement

<u>4.4 The drop off in performance is much more dramatic for lengths of design below the ideal than above.</u>

Fig 6. shows each resistance plotted as a percentage of the minimum resistance for that displacement against the length shown as a percentage of the length with the minimum resistance for the same displacement. Results for all three displacements are shown and it is apparent that there is a very tight fit, so much so that it is almost impossible to differentiate between them.

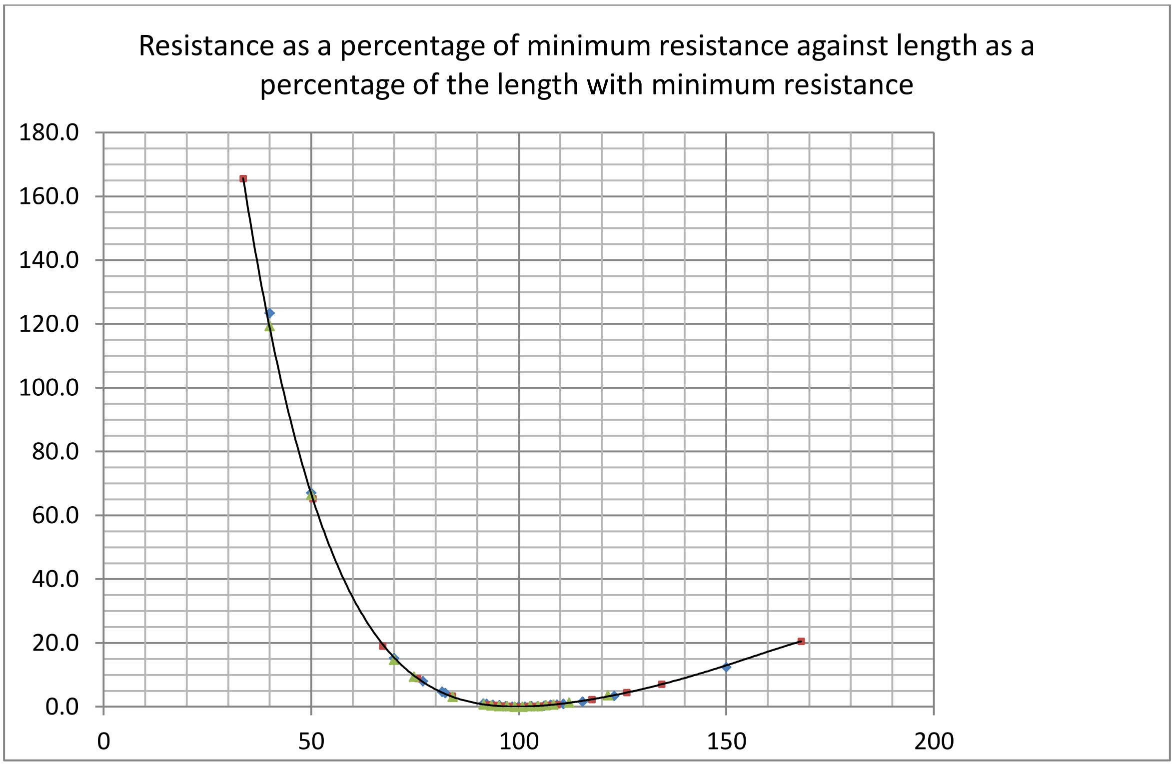


Figure 6

It can be seen that for a decrease of 40% in length there is roughly a 34% increase in resistance whereas a 40% increase gives and increase of roughly 10%. The difference is even more significant at a 60% decrease and increase in length with relative increases in resistance of around 120% and 17.5%.

Fig 6. also shows that for a change of around 10% above or below the optimum, there is only a very small percentage increase in resistance. This can be observed more clearly in the Fig 7. which focuses of that smaller range.

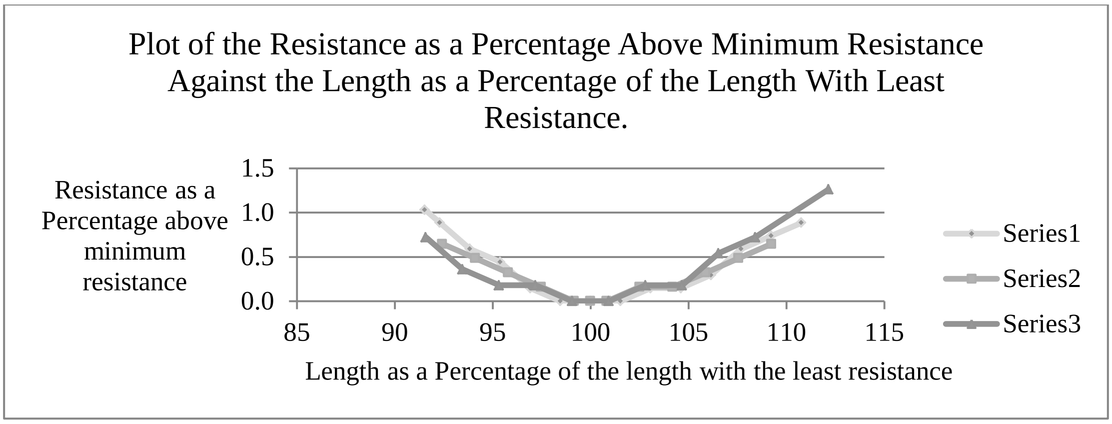


Figure 7

From here it is clear that there is a significant range of lengths that will not give more than a 1% increase in resistance above that of the absolute optimum. Therefore any length inside a range of between 0.5m and 0.7m either side of each ideal length only provides a maximum of 1% more resistance than that of the optimum length in each case.

4.5 The relationship between surface area and length is linear.

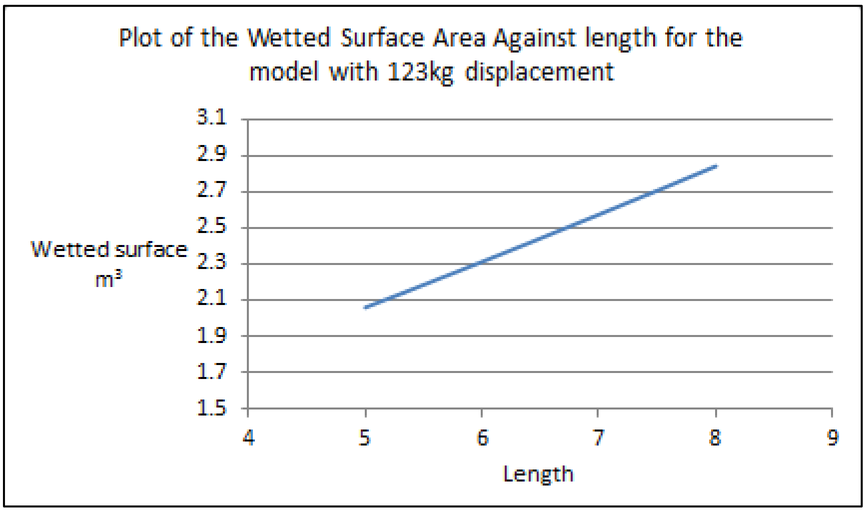


Figure 8

Fig 8 clearly shows that when the displacement is kept constant and length increases the way in which the surface area increases is linear.

4.6 Summary

- The optimum length for the three displacements of 82kg, 102.5kg and 123kg are 5.35, 5.95 and 6.5 respectively.
- the optimal length appears to increase with increasing required displacement.
- It is significantly more costly in terms of increased total resistance to have a boat shorter than the optimum rather than longer
- The significance of wave making resistance as a proportion of the total resistance appears to decline exponentially it decreases from making up as much as 70% at very short lengths of around 2m to less that 5% at longer lengths of around 10m.
- The increase in wetted surface area with length appears to be linear.

5. CONCLUSION

5.1 Aim

There are several aims of this section, firstly to give an unbiased view of the accuracy of the project. Secondly to discuss implications of the results in terms of how they relate to current designs of surf ski kayaks that are on the market today and how they might be of use to designers in the future. There will also be a discussion of possible future work that could be done following the results of this project.

5.2 Discussion of the accuracy

Before conclusions can be made, it has to be clear that there have been several assumptions made in order to complete this work. Any single assumption could have a noticeable impact on the final results therefore it has to be said that, given their number, the actual validity of the results should be questioned. Although this is true there are still some important conclusions to be drawn from the work.

The one result that does help to validate the method and the results for the prediction of the optimum length of the hull with a combined paddler and boat weight of 123kg. It is realistic to think that this boat will have a very similar displacement to that of the Epic V10 which was designed for and by Oscar Chalupsky(Chalupsky 2012). The combined weight of him plus his boat, the Epic V10 is around 121kg (Chalupsky 2012; Epic 2012) very close to that of the length found through optimisation for 123kg. The length of the V10 is 6.5m(Epic

2012), exactly the same as the optimised length for the mentioned. While it is not guaranteed that this result being very similar is proof that the method has been successful, it surely adds a certain amount of support to it.

5.3 Findings from the results

There is not a single optimum length

The first conclusion has to be that difficult to prescribe one optimum length. From the results in Fig 9 and Fig 10 alone it should be clear that the weight of the paddler, which is the biggest contributor to the total displacement, has a significant effect on the optimum length of the surf ski for that paddler.

Although an optimum can be found for a given weight of paddler there is a relatively wide range around that length that will not put the paddler at a significant disadvantage

From Fig 13 it is clearly shown that although there is a very small window, 10cm,of lengths that provides an absolute optimum lengths there is a much wider range of roughly 0.5m either side that will only give a maximum increase in resistance of just 1%. This is unlikely to be noticed by anyone except for the most elite paddler. Furthermore, the gain from having the perfectly optimised hull is so small that it could be easily be negated by a whole series of other factors from the hull not being completely clean to poor use of the rudder or minor tactical errors in the race.

It may be possible to optimise the length of a surf ski to better suit paddlers of different weights

The results in Figs 6, 7 and 8 have shown that it is possible to optimise the length of a boat by minimising the combined total of wave making and frictional resistance. This could be useful for athletes that are not heavy enough to maximise the gain of have a boat that is 6.5m long but still want to be able to achieve the highest speed possible for the power that they are able to put into the water.

In terms of the increase in resistance above a potential minimum, it is preferable to for a lighter paddler to use a boat that has been optimised for a heavier paddler than a heavier paddler to use a boat that has been optimised for a lighter person

The results show that there is more of an increase in resistance for a paddler using a boat that is shorter than optimum compared to being longer than their optimum. Because of this it is clear that it will be less detrimental for a person to paddle a boat that has been optimised for a greater displacement than they will provide than it is for the reverse situation to occur.

It is possible that this may be one of the reasons why thus far there has not been much interest in designing boats for different weight categories. It seems that a lot of the performance boats on the market have been developed to suit paddlers in the 110kg weight range. According to Fig 6 if a paddler weighing 36% less (70kg) were to use the same boat it would only have 3.6% more resistance than one optimised for their own weight may have. In the dynamic environment of the open ocean this may well go unnoticed whereas if the situation had been reversed and surf skis had been optimised with 70kg paddlers in mind, a 110kg paddler would experience up to 4.7% more than otherwise, a difference of 76%.

Current surf ski kayaks have been optimised but not for a wide range of people

From the results it may well be said that the designs of surfski on the market today have clearly been designed for big paddlers such as Oscar Chalupsky (Epic 2012). This would be true because according to the results a surfski with a displacement of $0.12m^3$ which roughly equates to a combined paddler plus boat weight of 122.5kg, the surf ski will have an optimum length somewhere between 6.4m and 6.5m. While this does make sense as Chalupsky is an 11 times world champion and would therefore demand the best equipment that he can get, it doesn't necessarily cater well for those that weigh less than his 110kg.

It is a sensible conclusion two paddlers with significantly different weights are not both going to perform to the best of their abilities while using the same boat. This must be particularly relevant when it comes to lighter men or female athletes in the sport. Because of this, there must surely be scope within the sport and within manufacturers to produce boats that are better optimised for individual athletes requirements.

Future work

Although there are flaws in this work that mean that the findings aren't necessarily accurate, the fundamental idea that the length of a surf ski could be better optimised depending on a paddlers weight is an important one. There are numerous ways in which this work could be built upon and a few of them are discussed below.

Towing tank tests of a various lengths of surf ski

It is possible that towing tank tests of full scale surf skis could be done in order to investigate more fully the effect of changing the length upon the resistance. The main problem with this is the vast expense that would be associated with it, it is highly unlikely that any one manufacturer would set out to do the tests, partly because it is unlikely that the money required would be returned in increased sales and also because any improvements that they found they could make would be quickly copied by other manufacturers.

Develop software capable of quickly finding the total resistance for a range of lengths speeds and displacements

The method of finding an optimum length in this project was particularly time consuming considering that the resistance had to be found for multiple lengths before it became clear which length had an optimum. It is quite feasible that software could be developed that could have an input of, for example, a paddlers weight and power output and it could then very quickly do all of the calculations for the same series of lengths and feedback the length that provides the least resistance.

Using a paddlers power output and weight to design a boat specifically suited to them

It is possible that with further research to prove the results found in this project it would give manufacturers the possibility of custom making boats to fit athletes personal requirements in terms of their weight and their power output. Although this would add significant cost to the process there would almost certainly be a market for such custom designs as experience says that when a sports person invests in equipment they will be looking to get the absolute maximum they can. This is particularly true of kayaking when many people will continue to use the same boat for many years.

Compare the resistance found for Wigley hull form with that of actual surfski or kayak hull

If, as predicted, there are significant similarities between the resistance of the Wigley hull form and that of the a surfski hull then this could simplify the process of deciding upon the optimum surf ski length considerably.

5.4 Review of the project and Summary

The project itself has had both its good and bad point. In terms of achieving the four aims set out at the beginning I feel that it has gone well. To recap, the aims were as follows

1. Develop an effective method for estimating the wave making and viscous resistance of a surfski.
2. To predict the optimum length a surf ski for a given velocity and displacement.
3. To investigate the effect, if any, that displacement has on the optimum length of a surfski.
4. To relate the estimated optimum lengths to the boats that are currently on the market.

In terms of developing an effective method for estimating the wave making and viscous resistance of a surfski, this has mostly been a success. It was not a complete success as there was only one method used and therefore no way of backing up the results with any other proof. However, that said, the optimum length predicted for the hull with a displacement of 123kg was particularly interesting as it matched so closely to the length of what is seen as a top quality boat (surfski.info 2012) (Epic 2012). It is also true that the method could be more fully developed by adding in such things as the Form factor which was neglected for this work but could have an impact on the result and before anyone considers using these result to design a boat these observations be taken into account.

The second aim of being able to predict the length of a surf ski for a given velocity and displacement is essentially covered in the previous paragraph. Predictions were made so in that sense it was more certain a success. The issue again comes down to the reliability of the results which cannot effectively be proven until further studies are made.

The third aim of investigating the affect that displacement has upon the optimum length I think is a full success. From the results it seems fairly clear that there will be a change in optimum length if there is a change in paddler weight. This does make sense logically as well, it seems unreasonable to expect a smaller paddler that has less muscle mass and power to be able to propel a long boat along as effectively as a bigger more powerful paddler. Similarly, I think if you place a big powerful paddler into a boat that’s too small then it’s unlikely that they will get the boat to work as effectively as a smaller lighter paddler.

It’s interesting to discuss if the final aim of comparing the results of this work to the boats found on the market has been a success. It is hard to say that it has been a complete success as it is difficult to prove that the results are accurate. However, with the almost perfect fit of the predicted length of 6.5m of the 123kg displacement boat with the Epic V10 of 6.5m and then the very accurate fit between Carbonology Sport Atom at 5.95m (Carbonology 2012) which is designed with ‘lighter’ paddlers in mind and the predicted length of the hull with 102.5kg displacement which was also 5.95m, it has to be more than a coincidence.

In conclusion I am happy with the project as a whole, there are always areas that can be improved on but, given the available resources, there are not too many areas that I would change. If there were more time I think it would be interesting and useful to look into the effects of form factor on the optimum resistance predicted and also the effects of spray resistance.

REFERENCES

1. Bai, K. J. (1979). "Overview of Results."
2. Baker, R. (2012). "A guide to Using the Michlet Software."
3. Carbonology (2012). "Carbonology Sport Surf Ski Specifications."
4. Carlton, J. (2007). Marine propellers and propulsion. Amsterdam ; Oxford, Elsevier Butterworth-Heinemann.
5. Chalupsky, O. (2012). "Chalupsky statistics."
6. Day, A., I. Campbell, et al. (2011). "Realistic evaluation of hull performance for rowing shells, canoes, and kayaks in unsteady flow." Journal of Sports Sciences **29**(10): 1059-1069.
7. E.O.Tuck (1989). "The Wave Resistance Formula of J.H.Michell and its Significance to Research in Ship Hydrodynamics."
8. Epic (2012). "Epic V10 Specification."
9. Froude, W. (1955). The Papers of William Froude. London, Institution of Naval Architects.
10. Gotman, A. (2002). "Study of Michell's Intergral and Influence of Viscosity and Ship Hull Form on Wave Resistance." Oceanic Engineering International **6**(2): 74-115.
11. Havelock, T. (1965). The collected papers of Sir Thomas Havelock on hydrodynamics. Washington,, Office of Naval Research Dept.
12. Holtrop, J. and R. O. Carter (1977). A statistical analysis of performance test results.
13. ICF (2010). "Canoe Ocean Racing." Retrieved 20/11/2011, 2011.
14. ITTC (1957). "Skin Friction and Turbulence Stimulation."
15. Lazauskas, E. T. a. L. (2008). "Drag on a Ship and Michell's Integral."
16. Lazauskas, L. (2011). "Michlet Software." (9.2).
17. Lazauskas, L., Winters, J and Tuck, E.O (1997). "Hydrodynamic Drag of Small Sea Kayaks."
18. Lewis, E. V. (1988). Principles of Naval Architecture. Jersey City, NJ, The society of Naval Architects and Marine Engineers.
19. Michell, J. H. (1898). "The Wave Resistance of a Ship." Philosophical Magazine **5**: 106-123.
20. Nelo (2012). "Nelo kayak specifications."
21. OpenAdventure (2011). "Results of 2011 open adventure ocean race."

22. Percival, S., D. Hendrix, et al. (2001). "Hydrodynamic optimization of ship hull forms." Applied Ocean Research **23**(6): 337-355.
23. Rooyen, H. V. (2011). R. Baker.
24. Sharma, S. D. (1969). "Some Results Concerning the Wavemaking of a Thin Ship." J Ship Research **13**: 72-81.
25. surfski.info (2012). "Surf Ski site, news, reviews results."
26. Tuck, E. O., Scullen, D.C and Lazauskas, L (2000). "Ship-Wave Patterns in the Spirit of Michell." Paper presented at IUTAM 2000, Birmingham.
27. Vajda (2010). "Vajda ORCA elite Pro Specification."
28. Vajda (2012). "Vajda sprint kayak specification."
29. Wang, H. and Z.-j. Zou (2008). "Numerical research on wave-making resistance of trimaran." Journal of Shanghai Jiaotong University (Science) **13**(3): 348-351.
30. Wigley, W. C. S. and William Froude Laboratory. (1936). The theory of the bulbous bow and its practical application. Newcastle upon Tyne
31. London, North East Coast Institution of Engineers and Shipbuilders ;
32. E. & F. N. Spon.
33. Zhang, D. and A. T. Chwang (1999). "On nonlinear ship waves and wave resistance calculations." Journal of Marine Science and Technology **4**(1): 7-15.

APPENDIX

Appendix 1. A Guide to Using the Michlet Software (Baker 2012)

When it first came to using the Michlet software it turned out to not be a simple process, when you open the program you cannot interact with it in the same way that you might expect to be able to if you were to use a any modern professional program. This does make the program tricky to use to as it takes a significant amount of time looking through the user manual in order to find out how to progress.

Before even opening the program it must be known that before any calculations can be made the offset data for the vessel that is being modelled must be first loaded into the input file which is named ‘in.mlt’ and shown highlighted in red in fig 9 and is found within the main Michlet folder this file is edited using ‘notepad’ or any other similar simple text editing program.

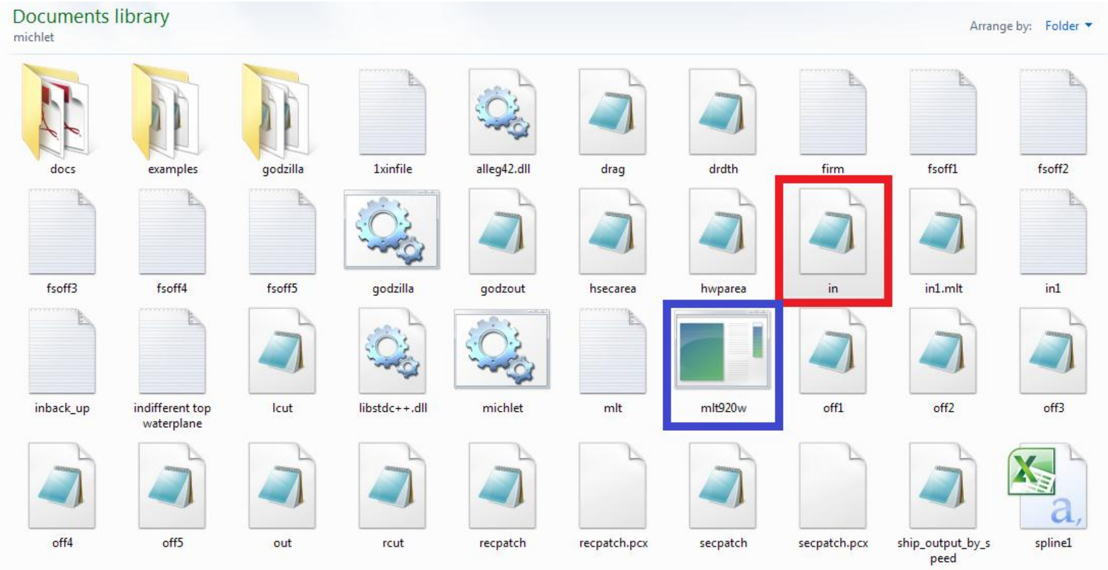


Figure 9

The program uses offset data to model any hull and the offsets can be of varying detail between 5 and 81 stations and 5 and 81 waterlines and the offsets given are for a half breadth model.

The model used for this work had 21 stations and 21 waterlines. These are shown in Fig 10

```
# =========================== FIRST HULL =============================
# Offsets
0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000
0.0000, 0.0028, 0.0055, 0.0080, 0.0104, 0.0127, 0.0148, 0.0167, 0.0185, 0.0202, 0.0217, 0.0231, 0.0243, 0.0254, 0.0264, 0.0271, 0.0278, 0.0283, 0.0287, 0.0289, 0.0290
0.0000, 0.0053, 0.0104, 0.0152, 0.0198, 0.0240, 0.0280, 0.0317, 0.0351, 0.0383, 0.0411, 0.0438, 0.0461, 0.0481, 0.0499, 0.0514, 0.0527, 0.0536, 0.0543, 0.0547, 0.0549
0.0000, 0.0076, 0.0148, 0.0216, 0.0280, 0.0340, 0.0396, 0.0449, 0.0497, 0.0542, 0.0583, 0.0620, 0.0653, 0.0682, 0.0707, 0.0729, 0.0746, 0.0760, 0.0769, 0.0775, 0.0777
0.0000, 0.0095, 0.0185, 0.0271, 0.0351, 0.0427, 0.0497, 0.0563, 0.0624, 0.0680, 0.0732, 0.0778, 0.0819, 0.0856, 0.0888, 0.0914, 0.0936, 0.0953, 0.0966, 0.0973, 0.0975
0.0000, 0.0111, 0.0217, 0.0317, 0.0411, 0.0500, 0.0583, 0.0660, 0.0732, 0.0797, 0.0857, 0.0912, 0.0960, 0.1003, 0.1040, 0.1072, 0.1097, 0.1117, 0.1132, 0.1140, 0.1143
0.0000, 0.0125, 0.0243, 0.0355, 0.0461, 0.0560, 0.0653, 0.0739, 0.0819, 0.0893, 0.0960, 0.1021, 0.1075, 0.1123, 0.1165, 0.1200, 0.1229, 0.1251, 0.1267, 0.1277, 0.1280
0.0000, 0.0135, 0.0264, 0.0385, 0.0499, 0.0607, 0.0707, 0.0801, 0.0888, 0.0967, 0.1040, 0.1106, 0.1165, 0.1217, 0.1262, 0.1300, 0.1331, 0.1356, 0.1373, 0.1383, 0.1387
0.0000, 0.0143, 0.0278, 0.0406, 0.0527, 0.0640, 0.0746, 0.0845, 0.0936, 0.1020, 0.1097, 0.1167, 0.1229, 0.1284, 0.1331, 0.1372, 0.1405, 0.1430, 0.1448, 0.1459, 0.1463
0.0000, 0.0147, 0.0287, 0.0419, 0.0543, 0.0660, 0.0769, 0.0871, 0.0966, 0.1052, 0.1132, 0.1203, 0.1267, 0.1324, 0.1373, 0.1414, 0.1448, 0.1475, 0.1494, 0.1505, 0.1509
0.0000, 0.0149, 0.0290, 0.0423, 0.0549, 0.0667, 0.0777, 0.0880, 0.0975, 0.1063, 0.1143, 0.1215, 0.1280, 0.1337, 0.1387, 0.1429, 0.1463, 0.1490, 0.1509, 0.1520, 0.1524
0.0000, 0.0147, 0.0287, 0.0419, 0.0543, 0.0660, 0.0769, 0.0871, 0.0966, 0.1052, 0.1132, 0.1203, 0.1267, 0.1324, 0.1373, 0.1414, 0.1448, 0.1475, 0.1494, 0.1505, 0.1509
0.0000, 0.0143, 0.0278, 0.0406, 0.0527, 0.0640, 0.0746, 0.0845, 0.0936, 0.1020, 0.1097, 0.1167, 0.1229, 0.1284, 0.1331, 0.1372, 0.1405, 0.1430, 0.1448, 0.1459, 0.1463
0.0000, 0.0135, 0.0264, 0.0385, 0.0499, 0.0607, 0.0707, 0.0801, 0.0888, 0.0967, 0.1040, 0.1106, 0.1165, 0.1217, 0.1262, 0.1300, 0.1331, 0.1356, 0.1373, 0.1383, 0.1387
0.0000, 0.0125, 0.0243, 0.0355, 0.0461, 0.0560, 0.0653, 0.0739, 0.0819, 0.0893, 0.0960, 0.1021, 0.1075, 0.1123, 0.1165, 0.1200, 0.1229, 0.1251, 0.1267, 0.1277, 0.1280
0.0000, 0.0111, 0.0217, 0.0317, 0.0411, 0.0500, 0.0583, 0.0660, 0.0732, 0.0797, 0.0857, 0.0912, 0.0960, 0.1003, 0.1040, 0.1072, 0.1097, 0.1117, 0.1132, 0.1140, 0.1143
0.0000, 0.0095, 0.0185, 0.0271, 0.0351, 0.0427, 0.0497, 0.0563, 0.0624, 0.0680, 0.0732, 0.0778, 0.0819, 0.0856, 0.0888, 0.0914, 0.0936, 0.0953, 0.0966, 0.0973, 0.0975
0.0000, 0.0076, 0.0148, 0.0216, 0.0280, 0.0340, 0.0396, 0.0449, 0.0497, 0.0542, 0.0583, 0.0620, 0.0653, 0.0682, 0.0707, 0.0729, 0.0746, 0.0760, 0.0769, 0.0775, 0.0777
0.0000, 0.0053, 0.0104, 0.0152, 0.0198, 0.0240, 0.0280, 0.0317, 0.0351, 0.0383, 0.0411, 0.0438, 0.0461, 0.0481, 0.0499, 0.0514, 0.0527, 0.0536, 0.0543, 0.0547, 0.0549
0.0000, 0.0028, 0.0055, 0.0080, 0.0104, 0.0127, 0.0148, 0.0167, 0.0185, 0.0202, 0.0217, 0.0231, 0.0243, 0.0254, 0.0264, 0.0271, 0.0278, 0.0283, 0.0287, 0.0289, 0.0290
0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000
```

Figure 10

The velocity at which the resistance will be calculated also must also be altered as required in the ‘in.mlt’ file, as should the displacement. It is recommended

The length and draft can be altered from within the Michlet program once it is running, this is done through a series of simple commands, to change the length the following procedure should be followed. To open the program, open the file named mlt920w highlighted in blue in Figure 9. Note that the ‘920’ part of the file name may change depending on the current version of the program so this may change in the future.

Changing the length of the vessel

1. Press ‘L’ (shift+l)
2. Enter the length required
3. Press ‘enter’

The task of altering the draft is slightly more complicated as the draft also effects the beam of the vessel. For the purposes of this project the beam was kept constant at 0.4500m. this meant carrying out an iterative process of altering the draft until the correct beam is found. The essential process is similar to that of the length though.

Changing the Draft and Beam of the Vessel

1. Press ‘T’ (shift+t)
2. Enter a value
3. Press enter

4. If the value for beam is too high return to step 1 and enter a higher draft value, if it is too low return to step 1 and enter a lower draft value, if it is correct the proceed to finding the resistance values. Beam is shown next to 'B' in the top right hand corner.
5. Once the draft that gives the correct beam for one length has been found, the process of finding the correct draft for any other length can be done using the following formula:

$$T_{new} = L_{old} / L_{new} * T_{old}$$

<u>Finding Values of Rt, Rv and Rw</u>

1. From the main screen press R (shift+r) to give options for Resistance Curves
2. For total resistance press 't', for wave resistance press 'w' and for viscous resistance press 'v'.
3. The max value of the y axis of the graph will give the resistance for the chosen component of resistance at the previously chosen velocity. To return back to choose an alternative graph press 'Esc' and return to step 2. To return back to the main screen press 'Esc' twice.

<u>Troubleshooting</u>

There were a couple of minor problems with the software along the way and as there didn't seem to be any online troubleshooting help, this small section details the problems as well as the solutions that were found to work

<u>Not responding to keys pressed</u>

There were several occasions when the Michlet program seemed to not be responding to keys being pressed, if this happens then, using the mouse, move the Michlet 'window' slightly and this should update the screen.

<u>'Esc' not working when trying to get back to the main screen from the resistance graphs.</u>

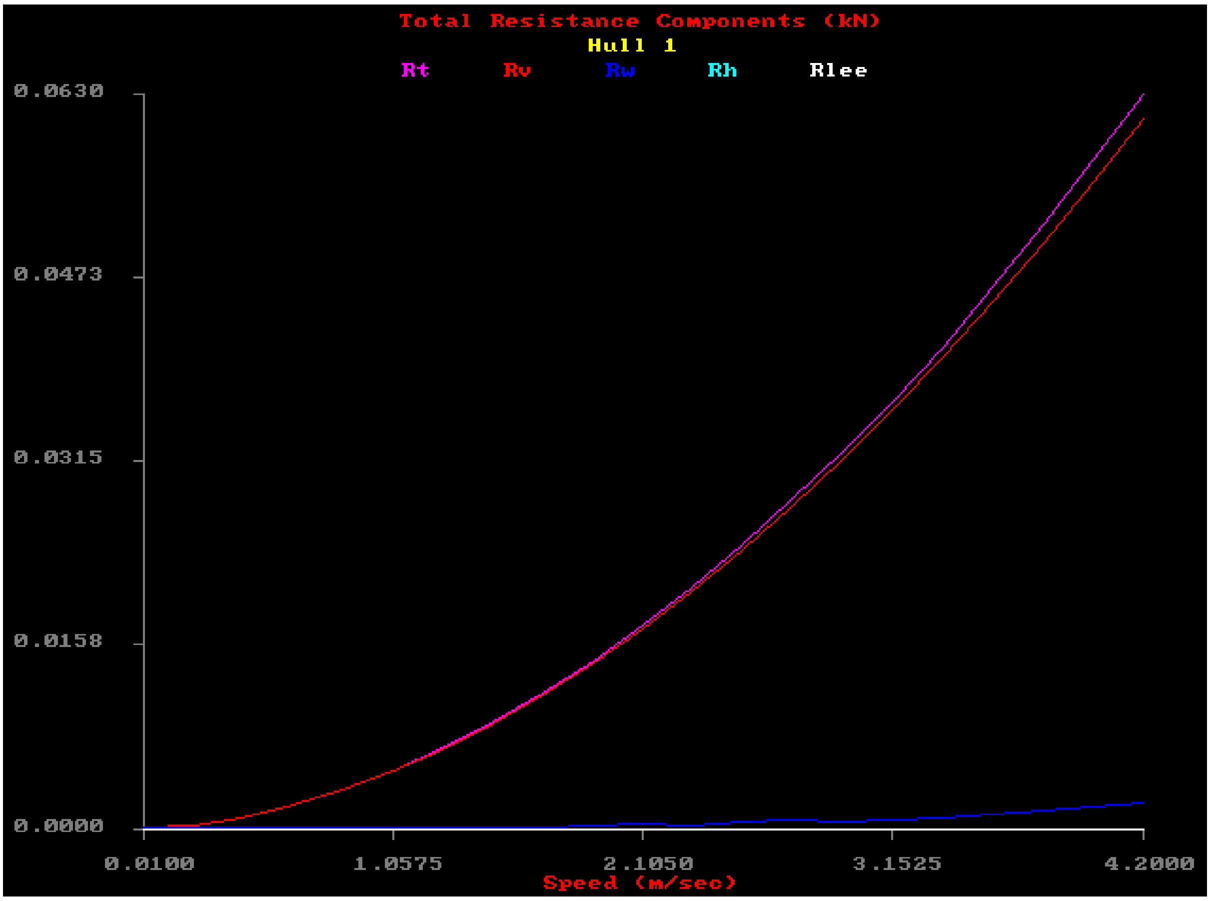
There were times when trying to leave the screen showing the resistance graphs that pressing 'Esc' didn't behave as it expected and failed to leave the screen. If or when this happens try pressing 'y' before pressing 'Esc' again.

Appendix 2 – Example resistance graphs from the Michlet Program

An example of the graph showing

- the total resistance in pink
- Viscous resistance in red
- Wake making resistance in blue

It is clear that this this graph is showing the resistance curves of a relatively long boat due to the very low proportion of wave making resistance.

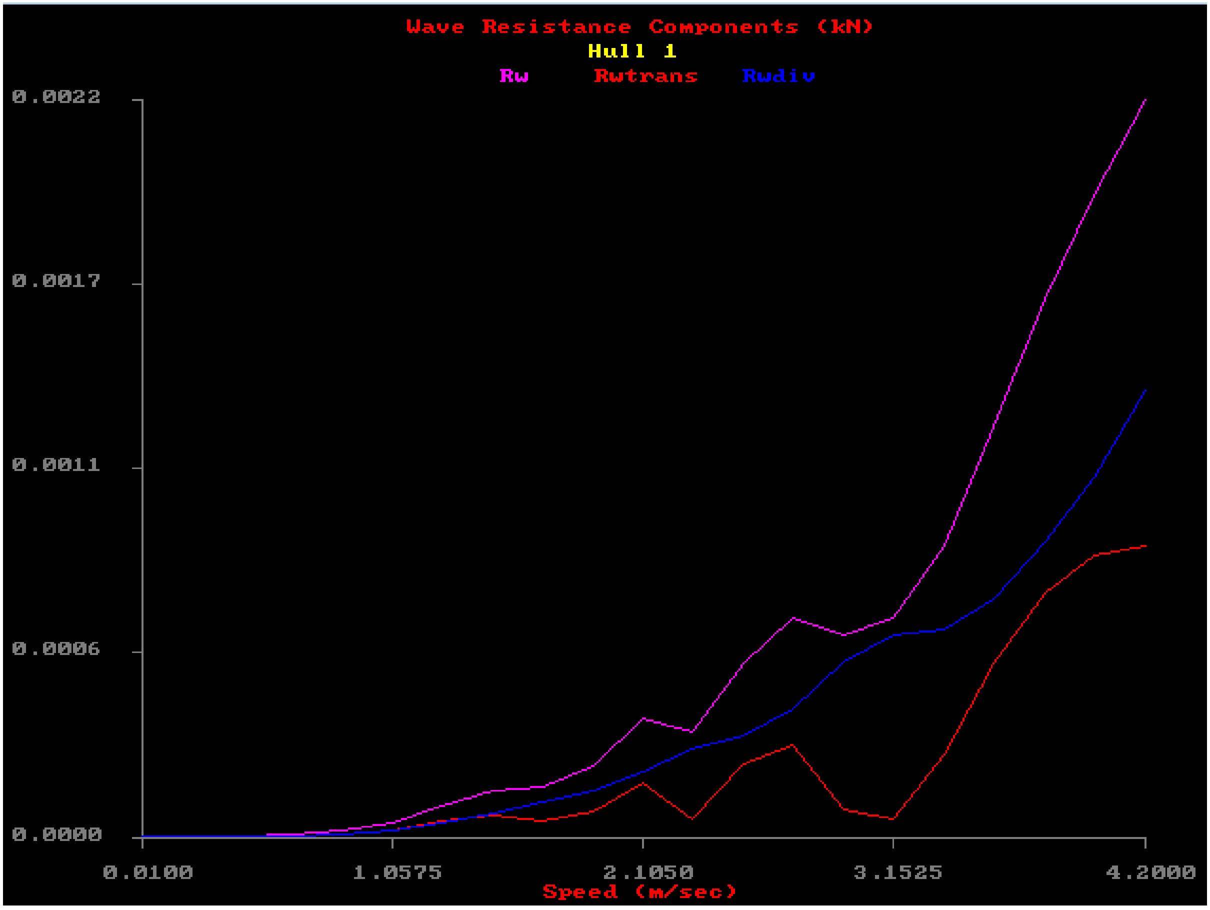


An example of a graph of the wave making resistance showing

Total wave making resistance in pink

Wave resistance from diverging waves in blue

Wave resistance from transverse waves in blue



An example of a graph showing the total viscous resistance

The viscous resistance (pink) and frictional resistance (blue) follow exactly the same path in this because the other factor in viscous resistance which comes from form factor is neglected.